

Two Aspects of the Mott-Hubbard Transition in Cr-doped V_2O_3

K. Held^a J. W. Allen^b V. I. Anisimov^c V. Eyert^d

G. Keller^d H.-D. Kim^e S.-K. Mo^b D. Vollhardt^d

^aMax-Planck-Institut für Festkörperforschung, 70569 Stuttgart, Germany

^bRandall Laboratory of Physics, University of Michigan, Ann Arbor, MI 48109, USA

^cInstitute of Metal Physics, Ekaterinburg GSP-170, Russia

^dInstitut für Physik, Universität Augsburg, 86135 Augsburg, Germany

^ePohang Accelerator Laboratory, Pohang 790-784, Korea

Abstract

The combination of bandstructure theory in the local density approximation with dynamical mean field theory was recently successfully applied to V_2O_3 – a material which undergoes the famous Mott-Hubbard metal-insulator transition upon Cr doping. The aim of this short paper is to emphasize two aspects of our recent results: (i) the filling of the Mott-Hubbard gap with increasing temperature, and (ii) the peculiarities of the Mott-Hubbard transition in this system which is not characterized by a divergence of the effective mass for the a_{1g} -orbital.

Key words: Strongly correlated electrons, Mott-Hubbard systems, orbital degrees of freedom

Introduction – A paradigm of electronic correlations is the Mott-Hubbard metal-insulator transition, triggered by an increasing ratio of Coulomb interaction over bandwidth (U/W). Experimentally, it is realized in paramagnetic V_2O_3 upon Cr-doping or decreasing pressure. Theoretically, the combination of the local density approximation and dynamical mean field theory (LDA+DMFT[1]) was successfully employed to this system recently [2], stimulating new experiments [3]. Here we restrict ourselves to two fascinating aspects of the transition: (i) the filling of the Mott-Hubbard gap with increasing temperature [3] and (ii) the peculiarities of the Mott-Hubbard transition due to the inequivalence of the a_{1g} - and e_g -orbitals [2].

(i) *Filling of the Mott-Hubbard gap with increasing temperature* – A feature genuine to a Mott-Hubbard insulator is that the zero temperature (T) Mott-Hubbard gap is filled with spectral weight when T is increased. In contrast, for a semiconducting or band insulator a gap stays a gap with increasing T ; only some electrons are statistically transferred across the gap because of finite T . How can we understand this non-intuitive feature of the Mott-Hubbard insulator? Let us

follow the two paths for metallic V_2O_3 and insulating $(V_{0.972}Cr_{0.028})_2O_3$ in the phase diagram Fig. 1a. If we consider a paramagnet instead of the antiferromagnetic insulator (AFI) at zero temperature, the paramagnetic metal (PM) is a Fermi liquid with a central quasiparticle resonance (point 0') and the insulator (PI) is gapped

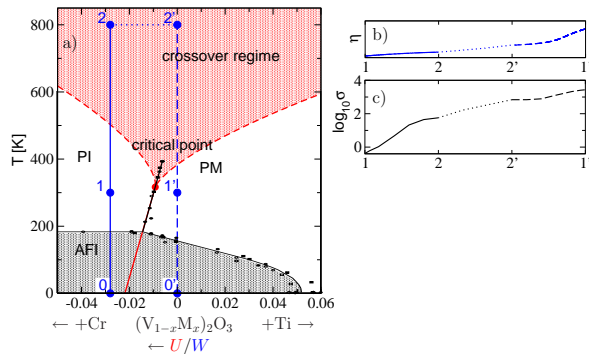


Fig. 1. a) Experimental (black/white) and DMFT (colors) phase diagram of V_2O_3 ; b) order parameter of the DMFT Landau theory and c) logarithm of the experimental conductivity (in units of $[\Omega\text{cm}]^{-1}$) along the paths of a) [reproduced from [3] with c) read off from [4]].

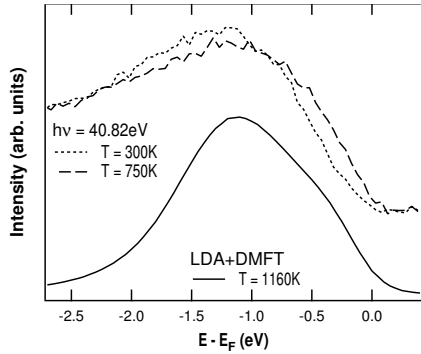


Fig. 2. Photoemission spectra showing the transfer of spectral weight into the Mott-Hubbard gap with increasing T and LDA+DMFT prediction [2] [reproduced from [3]].

(point 0). This picture changes only slightly if we increase T to points 1' and 1. When T is however further increased (to point 2') one enters the crossover regime, the quasiparticle peak fades away, and the lifetime becomes too short to speak of a quasiparticle peak anymore. Since the insulator and the metal are not distinct phases in the crossover regime, we see the Mott-Hubbard gap being filled with incoherent (short lifetime) spectral weight as one goes from point 1 to 2. This weight may be interpreted as a smeared out quasiparticle peak.

In Fig. 1b, the calculated [3] order parameter η of the DMFT Landau theory [5] is plotted. Since η corresponds to the spectral weight at the Fermi energy, it shows in detail the reduction of the metallic quasiparticle peak and the filling of the Mott-Hubbard gap along the lines from point 1' to 2' and from 1 to 2, respectively. As was pointed out in [3], this behavior is indeed seen in the experimental conductivity (Fig. 1c). Mo *et al.* [3] particularly observed for the first time the filling of the Mott-Hubbard gap with increasing T by photoemission spectroscopy, see Fig. 2, ascertaining the DMFT prediction.

(ii) *Peculiarities of the Mott-Hubbard transition* – Let us now turn to a different aspect of the Mott-Hubbard transition which stems from the orbital degrees of freedom. Within the Fermi-liquid metallic phase of V_2O_3 , the Green function is given by

$$G_m(\omega) = \int d\epsilon \frac{Z N_m^0(\epsilon)}{\omega + Z(\mu - \Re \Sigma_m(0) - \epsilon)} \quad (1)$$

at low frequencies ω . Here, $N_m^0(\epsilon)$ is the non-interacting (LDA) density of states (DOS) for $m = e_g^\pi$ or $m = a_{1g}$, Σ_m denotes the self energy and $Z_m = (1 - \partial \Re \Sigma_m(\omega) / \partial \omega|_{\omega=0})^{-1}$ the quasiparticle weight. In the one-band Hubbard model, the Mott-Hubbard transition is characterized by $Z \rightarrow 0$ at the critical value of U , or equivalently a divergence of the effective mass. The width of the quasiparticle peak goes

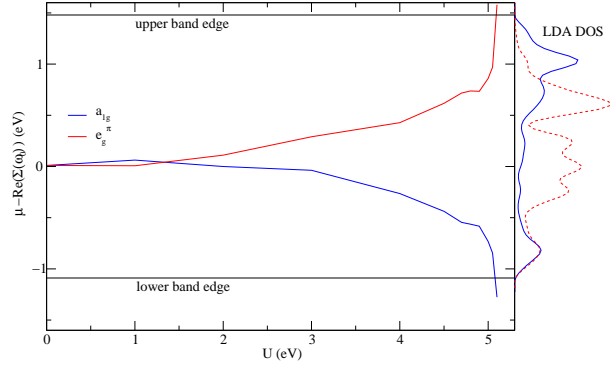


Fig. 3. The LDA+DMFT effective chemical potential $\mu - \Re \Sigma_m(\omega_0)$, for the a_{1g} - and e_g^π -orbitals (taken at the lowest Matsubara frequency ω_0) moves out of the band edges of the LDA DOS at the critical U for the Mott-Hubbard transition [reproduced from [2]].

to zero. Keller *et al.* [2] showed in their LDA+DMFT calculation that the Mott-Hubbard transition in V_2O_3 is actually different. While $Z_{e_g^\pi} \rightarrow 0$ for the two e_g^π -bands, $Z_{a_{1g}} \neq 0$ for the a_{1g} -band at the Mott-Hubbard transition. How can the a_{1g} -band then become insulating? Looking at Eq. (1), we see that there is another possibility consistent with the Fermi liquid metallic phase. The height of the quasiparticle peak is given by $N_m(\mu - \Re \Sigma_m(0))$. As is shown in Fig. 3, $\mu - \Re \Sigma_m(0)$ moves out of the non-interacting DOS at the Mott-Hubbard transition. Hence, the height of the quasiparticle peak goes to zero. For the a_{1g} quasiparticle peak, the height goes to zero at fixed width (which is already strongly reduced compared to $U = 0$). For the e_g^π -orbitals, the transition is characterized by a combined shrinking of width and height.

We acknowledge support of the DFG through the Emmy Noether program and SFB 484, U.S. NSF at the University of Michigan (UM) (Grant No. DMR-03-02825), and KOSEF through eSSC at POSTECH.

References

- [1] V. I. Anisimov *et al.*, A. I. Poteryaev, M. A. Korotin, A. O. Anokhin, and G. Kotliar, J. Phys. Cond. Matter **9**, 7359 (1997); A. I. Lichtenstein and M. I. Katsnelson, Phys. Rev. B **57**, 6884 (1998); for a review see K. Held *et al.*, Psi-k Newsletter #56, 65 (2003) [<http://psi-k.dl.ac.uk/newsletters/News56/Highlight56.pdf>].
- [2] K. Held *et al.*, Phys. Rev. Lett. **86**, 5345 (2001); G. Keller *et al.*, cond-mat/0402133.
- [3] S.-K. Mo *et al.*, Phys. Rev. Lett. **90**, 186403 (2003); Phys. Rev. Lett. in print [cond-mat/0403094].
- [4] H. Kuwamoto, J. M. Honig, and J. Appel, Phys. Rev. B **22**, 2626 (1980).
- [5] G. Kotliar, E. Lange, and M. Rozenberg, Phys. Rev. Lett. **84**, 5180 (2000).